TT 27: Transport: Quantum Coherence and Quantum Information Systems - Theory 1 (Joint session of HL, MA and TT organized by TT)

Time: Tuesday 9:30–12:45 Location: H22

TT 27.1 Tue 9:30 H22

Measurement-induced entanglement of two transmon qubits by a single photon — Christoph Ohm and •Fabian Hassler — JARA Institute for Quantum Information, RWTH Aachen University, 52056 Aachen

On-demand creation of entanglement between distant qubits is desirable for quantum communication devices but so far not available for superconducting qubits. We propose an entanglement scheme that allows for single-shot deterministic entanglement creation by detecting a single photon passing through a Mach-Zehnder interferometer with one transmon qubit in each arm. The entanglement production essentially relies on the fact that superconducting microwave structures allow to achieve strong coupling between the qubit and the photon. By detecting the photon via a photon counter, a parity measurement is implemented and the wave function of the two qubits is projected onto a maximally entangled state. Moreover, due to the indivisible nature of single photons, our scheme promises full security for entanglement-based quantum key distribution.

TT 27.2 Tue 9:45 H22

Quantum Chemistry on a Superconducting Quantum Processor — •Michael P. Kaicher[1], Frank K. Wilhelm[1], and Peter J. Love[2] — [1]Theoretical Physics, Saarland University, 66123 Saarbruecken, Germany — [2]Department of Physics and Astronomy, Tufts University, Medford, MA 02155, USA

Quantum chemistry is the most promising civilian application for quantum processors to date. We study its adaptation to superconducting (sc) quantum systems, computing the ground state energy of LiH through a variational hybrid quantum classical algorithm. We demonstrate how interactions native to sc qubits further reduce the amount of quantum resources needed, pushing sc architectures as a near-term candidate for simulations of more complex atoms/molecules.

TT 27.3 Tue 10:00 H22

Optimization of Quantum Microwave Photodetection for circuit QED applications — •Marius Schöndorf[1], Luke C. Govia[1,3], Maxim Vavilov[2], Robert McDermott[2], and Frank K. Wilhelm[1] — [1]Universität des Saarlandes, Saarbrücken, Deutschland — [2]University of Wisconsin, Madison, USA — [3]McGill University, Montreal, Canada

Superconducting qubits are a promising candidate architecture for quantum computing and information. Readout of the qubit state is an important step that has to be taken for realising quantum algorithms in experiment. Recently we presented a qubit readout scheme [1] using a device called Jospehson Photomultiplier (JPM) [2]. One main step in this architecture is to read out a light state of a transmission line with the JPM. In this work we present a guide how to tune the different parameters in the experiment to optimize the measurement efficiency. We use Input-Output Theory to look at a continuous driven transmission line as well as various pulse states. Using analytical and numerical mehtods, we calculate conditions on the different parameters to optimize the respective measurement.

[1] L. C. G. Govia et al., PRA **92**, 022335 (2015)
[2] Y.-F. Chen et al., PRL **107**, 217401 (2012)

TT 27.4 Tue 10:15 H22

Theory and practice of dressed coherent states in circuit QED — •Frank Wilhelm[1] and Luke C. G. Govia[1,2] — [1]Theoretical Physics, Saarland University, Campus E 2.6, 66123 Saarbrücken, Germany — [2]Department of Physics, McGill University, Montreal, Canada

In the dispersive regime of qubit-cavity coupling, classical cavity drive populates the cavity, but leaves the qubit state unaffected. However, the dispersive Hamiltonian is derived after both a frame transformation and an approximation. Therefore, to connect to external experimental devices, the inverse frame transformation from the dispersive frame back to the lab frame is necessary. We show that in the lab frame the system is best described by an entangled state known as the dressed coherent state, and thus even in the dispersive regime, entanglement is generated between the qubit and the cavity. Also, we show that further qubit evolution depends on both the amplitude and phase of the dressed coherent state. This provides a limitation to readout in the dispersive regime. We show that only in the limit of infinite measurement time is this protocol QND, as the formation of a dressed coherent state in the qubit-cavity system applies an effective rotation to the qubit state. We show how this rotation can be corrected by a unitary operation, leading to improved qubit initialization by measurement and unitary feedback.

[1] L. C. G. Govia and F.K. Wllhelm,
Phys. Rev. Appl. **4**, 054001 (2015)
[2] L. C.G. Govia and F.K. Wilhelm, arXiv: 1506.04997

TT 27.5 Tue 10:30 H22

Gradient optimization for analytic controls — •Elie Assémat[1], Shai Machnes[2], David Tannor[2], and Frank Wilhelm-Mauch[1] — [1]Saarland University, Saarbrücken, Germany — [2]Weizmann Institute of Science, Rehovot, Israël

Quantum optimal control becomes a necessary step in a growing number of studies in the quantum realm. Recent experimental advances showed that superconducting qubits can be controlled with an impressive accuracy. However, most of the standard optimal control algorithms are not designed to manage such high accuracy. To tackle this issue, a novel quantum optimal control algorithm have been introduced: the Gradient Optimization for Analytic conTrols (GOAT). It avoids the piecewise constant approximation of the control pulse used by standard algorithms. This allows an efficient implementation of very high accuracy optimization. It also includes a novel method to compute the gradient that provides many advantages, e.g. the absence of backpropagation or the natural route to optimize the robustness of the control pulses. This talk will present the GOAT algorithm and a few applications to transmons systems.

TT 27.6 Tue 10:45 H22

Optimal control of single flux quantum (SFQ) pulse sequences — •Per J. Liebermann and Frank K. Wilhelm — Universität des Saarlandes, Saarbrücken

Single flux quantum (SFQ) pulses are a natural candidate for on-chip control of superconducting qubits [1]. High accuracy quantum gates are accessible with quantum optimal control methods. We apply trains of SFQ pulses to operate single qubit gates, under the constraint of fixed amplitude and duration of each pulse. Timing of the control pulses is optimized using genetic algorithms and simulated annealing, decreasing the average fidelity error by several orders of magnitude. Furthermore we are able to reduce the gate time to the quantum speed limit. Leakage out of the qubit subspace as well as timing errors of the pulses are considered, exploring the robustness of our optimized sequence. This takes us one step further to a scalable quantum processor.

[1] R. McDermott, M.G. Vavilov, Phys. Rev. Appl. **2**, 014007 (2014)

TT 27.7 Tue 11:00 H22

Nonlinearities in Josephson-Photonics — •Björn Kubala and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, Ulm University, Ulm, Germany

Embedding a voltage-biased Josephson junction within a high-Q superconducting microwave cavity provides a new way to explore the interplay of the tunneling transfer of charges and the emission and absorption of light. While for weak driving the system can be reduced to simple cases, such as a (damped) harmonic or parametric oscillator, the inherent nonlinearity of the Josephson junction allows to access regimes of strongly non-linear quantum dynamics.

Classically, dynamical phenomena such as thresholds for higher-order resonances, other bifurcations, and up- and down-conversion have been found [1]. Here, we will investigate how and to which extent these features appear in the deep quantum regime, where charge quantization effects are crucial. Theory allows to employ phase-space quantities, such as the Wigner-density of the cavity mode(s) [2], but also observables amenable to more immediate experimental access, such as correlations in light emission and charge transport, to probe these novel non-equilibrium transitions.

[1] S. Meister, M. Mecklenburg, V. Gramich, J. T. Stockburger,

J. Ankerhold, B. Kubala, PRB **92**, 174532 (2015).
[2] A. D. Armour, B. Kubala, J. Ankerhold, PRB **91**, 184508 (2015).

15 min. break

TT 27.8 Tue 11:30 H22

Normal-metal quasiparticle traps for superconducting qubits
— •Amin Hosseinkhani — Peter Grunberg Institute (PGI-2), Forschungszentrum Julich, D-52425 Julich, Germany — JARA-Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany

Superconducting qubits are promising candidates to implement quantum computation, and have been a subject of intensive research in the past decade. Excitations of a superconductor, known as quasiparticles, can reduce the qubit performance by causing relaxation; the relaxation rate is proportional to the density of quasiparticles tunneling through Josephson junction. Here, we consider engineering quasiparticle traps by covering parts of a superconducting device with normal-metal islands. We utilize a phenomenological quasiparticle diffusion model to study both the decay rate of excess quasiparticles and the steady-state profile of the quasiparticle density in the device. We apply the model to various realistic configurations to explore the role of geometry and location of the traps.

TT 27.9 Tue 11:45 H22

Decoherence and Decay of Two-level Systems due to Non-equilibrium Quasiparticles
— •Sebastian Zanker, Michael Marthaler, and Gerd Schön — Karlsruher Institut für Technologie, Institut für Theoretische Festkörperpgysik, Karlsruhe, Deutschland

It is frequently observed that even at very low temperatures the number of quasiparticles in superconducting materials is higher than predicted by standard BCS-theory. These quasiparticles can interact with two-level systems, such as superconducting qubits or two-level systems (TLS) in the amorphous oxide layer of a Josephson junction. This interaction leads to decay and decoherence of the TLS, with specific results, such as the time dependence, depending on the distribution of quasiparticles and the form of the interaction. We study the resulting decay laws for different experimentally relevant protocols.

TT 27.10 Tue 12:00 H22

Theory of the double Quantum-dot Maser
— •Clemens Müller and Thomas M. Stace — ARC Centre of Excellence for Engineered Quantum Systems, The University of Queensland, Brisbane, Australia

We consider a voltage-biased double quantum-dot (DQD) in the transport regime, dipole-coupled to a superconducting microwave cavity [1, 2]. We explore the effect of dissipative coupling of the DQD to a phononic environment and its influence on microwave gain and loss observed in the resonator. To this end, we develop a rate equation based on fourth-order perturbation theory in the dissipative and coherent DQD interactions. We compare our findings with the recent paper Ref.[3], where a different technique based on the Polaron transformation was used.

[1] Y.-Y. Liu, K. D. Petersson, J. Stehlik, J. M. Taylor, and J. R. Petta, PRL **113**, 036801 (2014)
[2] Y.-Y. Liu, J. Stehlik, C. Eichler, M. J. Gullans, J. M. Taylor, J. R. Petta, Science **347**, 285 (2015)
[3] M. J. Gullans, Y.-Y. Liu, J. Stehlik, J. R. Petta, J. M. Taylor, PRL **114**, 196802 (2015)

TT 27.11 Tue 12:15 H22

Upper bound for SL-invariant entanglement measures for mixed states of arbitrary rank
— •Andreas Osterloh — Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany.

I present an algorithm that calculates an SL-invariant entanglement measure E as the threetangle of a mixed state of arbitrary rank. It is an alternative algorithm to ref. [1] and exploits the knowledge obtained for the rank-two case [2,3]. Whereas the known algorithm has an advantage of taking into consideration the whole range of the density matrix ρ, it on the other hand has the disadvantage of searching in a high-dimensional Hilbert space. Here, I only consider ensembles of two states each time but then calculate the upper bound obtained by the method presented in [2,3]. I discuss examples where the advantage of the new algorithm is obvious, but also highlight the obvious disadvantage of only considering rank two parts of ρ.

[1] S. Rodriques, N. Datta, and P. Love, PRA **90**, 012340 (2014)
[2] R. Lohmayer, A. Osterloh, J. Siewert, and A. Uhlmann, PRL **97**, 260502 (2006)
[3] A. Osterloh, J. Siewert, and A. Uhlmann, PRA **77**, 032310 (2008).

TT 27.12 Tue 12:30 H22

Occupation number entanglement in mesoscopic conductors
— •David Dasenbrook[1] and Christian Flindt[2] — [1]Université de Genève, Genève, Switzerland — [2]Aalto University, Finland

The controlled entanglement of electrons in mesoscopic conductors has been theoretically investigated before using the spin- and orbital degrees of freedom. By contrast, entanglement of two spatially separated electronic channels using the fermionic occupation number has mostly been considered inaccessible due to the charge superselection rule. However, using non-local measurements or combining several copies of occupation number entangled states, the superselection rules can be lifted and the entanglement can be detected using current and noise measurements. We present the theory for an interferometric setup to detect entanglement in the electron-hole degree of freedom of electronic excitations[1] as well as a mesoscopic setup that demonstrates entanglement and nonlocality of a single electron[2].

[1] D. Dasenbrook and C. Flindt, PRB **92**, 161412(R) (2015)
[2] D. Dasenbrook, J. Bowles, J. Bohr Brask, P. P. Hofer, C. Flindt, and N. Brunner, arXiv:1511.04450 (2015)